

AUTONOMOUS POWER EXPERT FAULT DIAGNOSTIC SYSTEM FOR SPACE STATION FREEDOM ELECTRICAL POWER SYSTEM TESTBED

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ABSTRACT

The goal of the Autonomous Power System (APS) program is to develop and apply intelligent problem solving and control to the Space Station Freedom Electrical Power System (SSF/EPS) testbed being developed and demonstrated at NASA Lewis Research Center. The objectives of the program are to establish artificial intelligence technology paths, to craft knowledge-based tools with advanced human-operator interfaces for power systems, and to interface and integrate knowledge-based systems with conventional controllers.

The Autonomous Power Expert (APEX) portion of the APS program will integrate a knowledge-based fault diagnostic system and a power resource planner-scheduler. Then APEX will interface on-line with the SSF/EPS testbed and its Power Management Controller (PMC). The key tasks include establishing knowledge bases for system diagnostics, fault detection and isolation analysis, on-line information accessing through the PMC, enhanced data management, and multiple-level, object-oriented operator displays. The first prototype of the diagnostic expert system for fault detection and isolation has been developed.

This paper describes the knowledge bases and the rule-based model that has been developed for the Power Distribution Control Unit subsystem of the SSF/EPS testbed. A corresponding troubleshooting technique is also described.

INTRODUCTION

This paper is limited to the Autonomous Power Expert (APEX) system, which is one of the major parts of the Autonomous Power System (APS) project under development at NASA Lewis Research Center, Cleveland, Ohio. The project is a joint effort of the Space Electronics, Power Technology, and Electrical Systems Divisions to develop and demonstrate the application of expert systems technology with a focus on the Space Station Freedom Electrical Power System (SSF/EPS) testbed.

APEX was designed as a high-level advisor for diagnosing faults in the Power Distribution Control Unit (PDCU), which is a major subsystem of the SSF/EPS testbed. The rule base and model of

this subsystem were built based on both dynamic and static knowledge of the system configuration and the remote power-control devices (20 kHz Remote Power Isolator and Remote Power Controller, manufactured by Westinghouse Corp., Lima, Ohio). These remote power-control devices are used throughout the SSF/EPS testbed for controlling, protecting, and monitoring the power distribution traffic. An operational prototype of the expert system fault detection, isolation, and justification package was recently completed and tested successfully. Figure 1 shows the proposed integration of the APEX system with other subsystems (ref. 1).

Descriptions of the system knowledge bases, rule base and model, and troubleshooting technique are presented in the following sections.

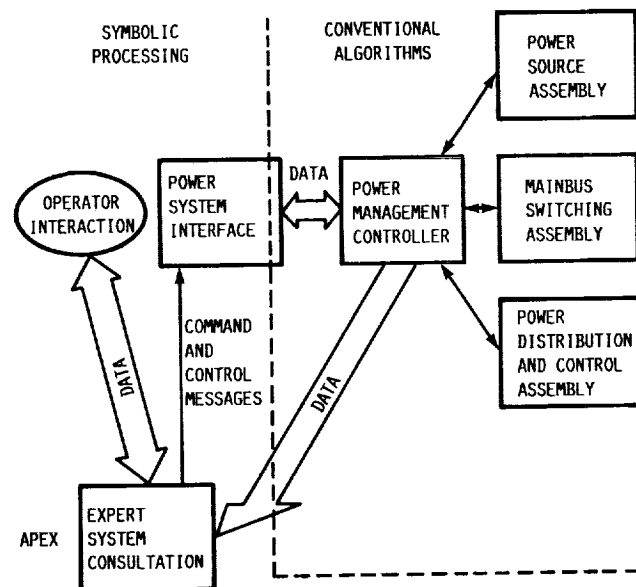


FIGURE 1. - AUTONOMOUS POWER SYSTEM INTEGRATION PLAN SHOWING AUTONOMOUS POWER EXPERT (APEX) SYSTEM.

SYSTEM KNOWLEDGE BASES

Design Activities

APEX is a knowledge-based system consisting of multiple knowledge bases that contain rules, facts, and graphic representations. To organize the data and to facilitate ease of maintenance and extendibility, we decided to use multiple knowledge bases. There are, therefore, four knowledge bases: one for the rules and facts, one for the user interface, and two containing graphic structures for human-interface panels.

The design of APEX is based on two primary requirements. The first is continuous monitoring of parametric data for incipient fault prediction. This type of monitoring requires retaining a history of data that can be checked for problems by trend analysis. The second requirement is multiple fault analysis of complicated failure modes. Conditions can occur that cause multiple failures in the system. These multiple failures can occur so quickly and generate so much data that only experts can analyze the resulting condition of the power system and take the appropriate actions to restore power. The objective for APEX is to capture the knowledge of the experts for these complicated situations and make the knowledge available to others who are responsible for the power system control.

Since the SSF/EPS is currently under design, not all of the diagnostic expert knowledge about the system is available. APEX will initially contain the current knowledge of the domain experts, but it will be extended to maturity as new knowledge is gained. By capturing the knowledge as it becomes available, APEX will retain and document new knowledge, as well as making it accessible to others.

In reference 2, expert systems are commonly developed on the basis of vague requirements. A general requirement to develop a system that does what the expert does is typical. For the APEX system, two specific requirements were identified before prototype development activity began: (1) incipient fault prediction and (2) multiple fault analysis. Specific functionality to meet these requirements was postponed until the prototype development phase of the project.

Architecture Selection

It was clear after several interview sessions with domain experts that the diagnostic procedural knowledge was best represented by a rule-based approach. The troubleshooting techniques that the experts use involve an "if something, then do" logic procedure to isolate faults in the system. An expert system development tool with the same logic capability was selected to help develop the prototype diagnostic system. The expert system tools being used for this development are the Knowledge Engineering Environments (KEE) software package by Intellicorp, Inc. (ref. 3), and the Texas Instruments (TI) Explorer II LX (trademark of Texas Instruments Corp.) computer workstation.

RULE BASE AND MODEL

Prototype Activities

We decided to model a correctly operating power system and to check primary data parameters to detect faults. As long as monitored data values were within tolerance according to the model, no rule firing was necessary. A combined forward-chaining (data driven) and backward-chaining (goal driven) approach was selected. Forward chaining was used for fault detection. Backward chaining with appropriate sets of rules for detecting faults was used for isolating probable causes of the faults. The rules were based on an up-to-date model of the PDCU. A frame-based inheritance network was used to represent the model.

A structured representation of all system components and their attributes was included in the model. Functional, behavioral, and physical properties of the components, as well as the interconnections between components, were represented. Upward and downward data trends were the primary bases for identifying incipient failure modes. Behavioral properties were used to describe current state information as well as expectations upon the occurrence of multiple faults.

A system for diagnosing fault conditions in a particular problem domain must know the limits of its capabilities and inform a human user of any problems. Many rules have been developed to detect when APEX is reasoning with inconsistent information that is not valid within its domain. A simple example of this phenomena is power output from a device that is "off" according to status information. Such information is often difficult to encapsulate in any type of program and can cause inappropriate rule firing leading to incorrect conclusions. Much effort was made to avoid any situations that could mislead an operator.

The knowledge base can be extended to include additional rules and diagnostic procedures as new knowledge becomes available.

Parametric Data Simulation

Parametric data available from the electrical power system testbed instrumentation include analog and digital data values. The analog values are power, voltage, current, and phase angle at various test points. The digital values provide status information. For prototyping purposes, a software simulator was developed to provide data for testing the expert system. Simulated data can be conveniently generated via a mouse-activated simulator panel as shown on Figure 2.

Features of the simulator include initialization of the system, fault injection, and automatic calculation of parametric data for all test points of the PDCU. Initialization sets the system to a steady-state, no-fault configuration. Fault injection provides a method to generate fault conditions. Test point data are calculated automatically by engineering algorithms that simulate the behavior of the PDCU circuitry.

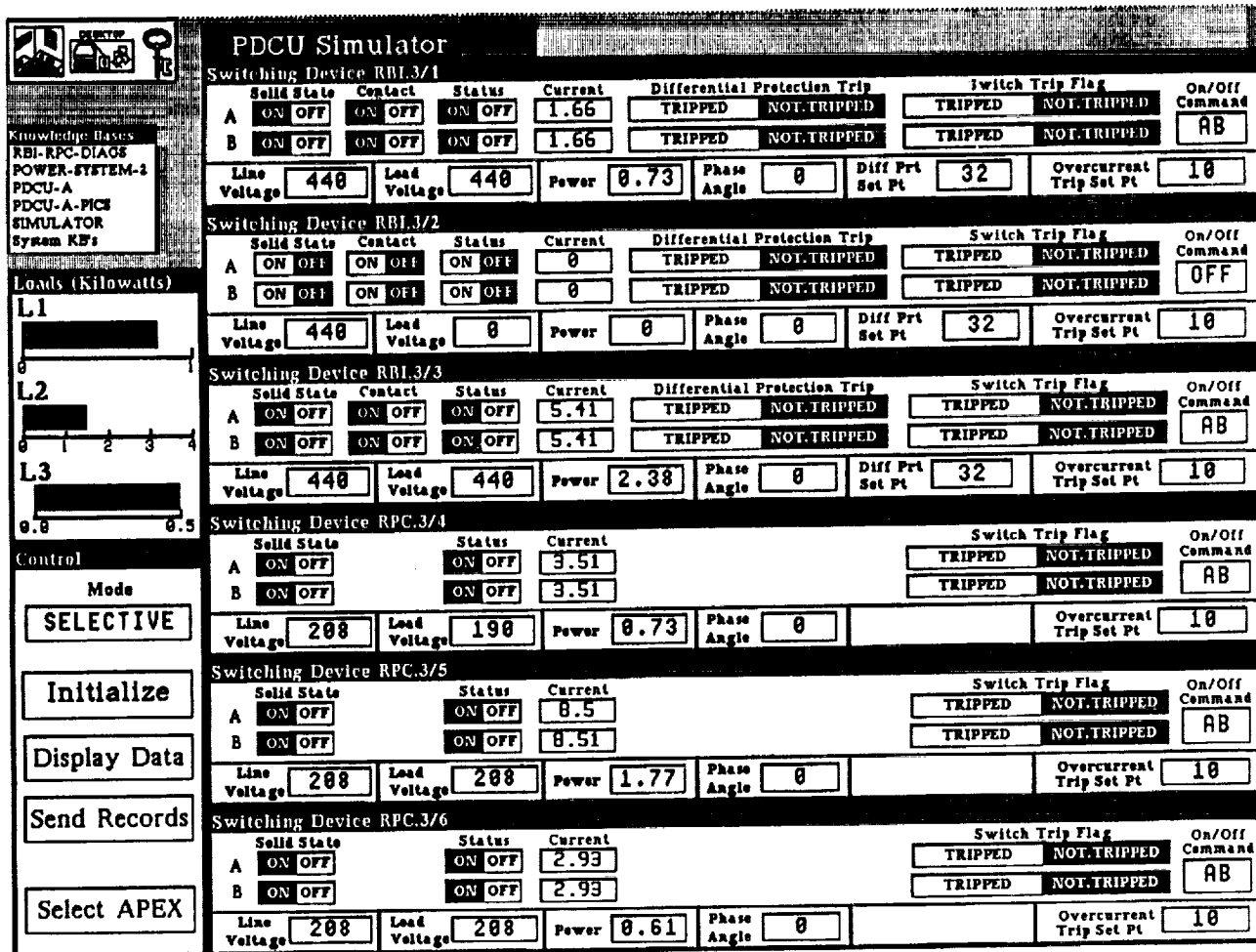


FIGURE 2. - DISPLAY OF AUTONOMOUS POWER EXPERT (APEX) POWER DISTRIBUTION CONTROL UNIT SIMULATOR.

Simulated data values are written to a memory area that is shared by the expert system via a blackboard communication interface. During the next phase of the project, the PMC will replace the simulator. After APEX is interfaced with the PMC for further development, actual data will be read and communicated to the same blackboard interface.

TROUBLESHOOTING TECHNIQUE

All identifiable faults in the PDCU can be detected and isolated. These faults include failures in individual or combinations of power sources, remote bus isolators, remote power controllers, transformers, transmission lines, and electrical loads. The troubleshooting technique has three main features: fault detection, isolation of probable causes, and justification for the probable causes.

Within the framework of the diagnostic knowledge base, the rules are organized into separate frames for detection and isolation. Forward chaining, driven by changing data in the blackboard communications memory area detects faults within the sys-

tem. Faults can either be caused by parametric data that falls outside of the desired model, or a trend in the data that indicates an incipient failure. Backward chaining is used to reach conclusions concerning fault conditions.

Justification retrieves the reasoning path used to reach conclusions and displays natural language explanations of the reasoning. The explanations are used to justify conclusions to the operator. The natural language interface was developed in LISP (LIST Processing language) with schema functions linked to the rules in the knowledge base. Rules that fire during fault isolation are retrieved in the order that they fired and are linked to natural language explanations by the schema functions.

The natural language explanations appear on several of the operator panel displays. Some of the explanations have further justifications that provide deeper levels of explanation. Complete explanations of the reasoning used to reach conclusions is provided through the schema-based natural language interface.

Human-interface panels provide three levels of information accessing to the system. The highest level of access is a two-panel display that consists of an operator panel and a mouse-activated panel showing the power system overall block diagram. Figure 3 is a hard copy of the APEX top level display. The operator panel provides operator controls for activating blackboard monitoring, detecting faults, isolating causes, requesting justification, and printing out desired information. Mousing on subsystem displays of the PDCU

overall block diagram panel provides access to lower-level subsystem block diagrams and circuit schematics as shown in Figures 4 and 5, respectively.

All of the displays automatically highlight any problem areas and specific fault locations. These highlighted blocks provide information to the operator and display current data values from the blackboard memory area.

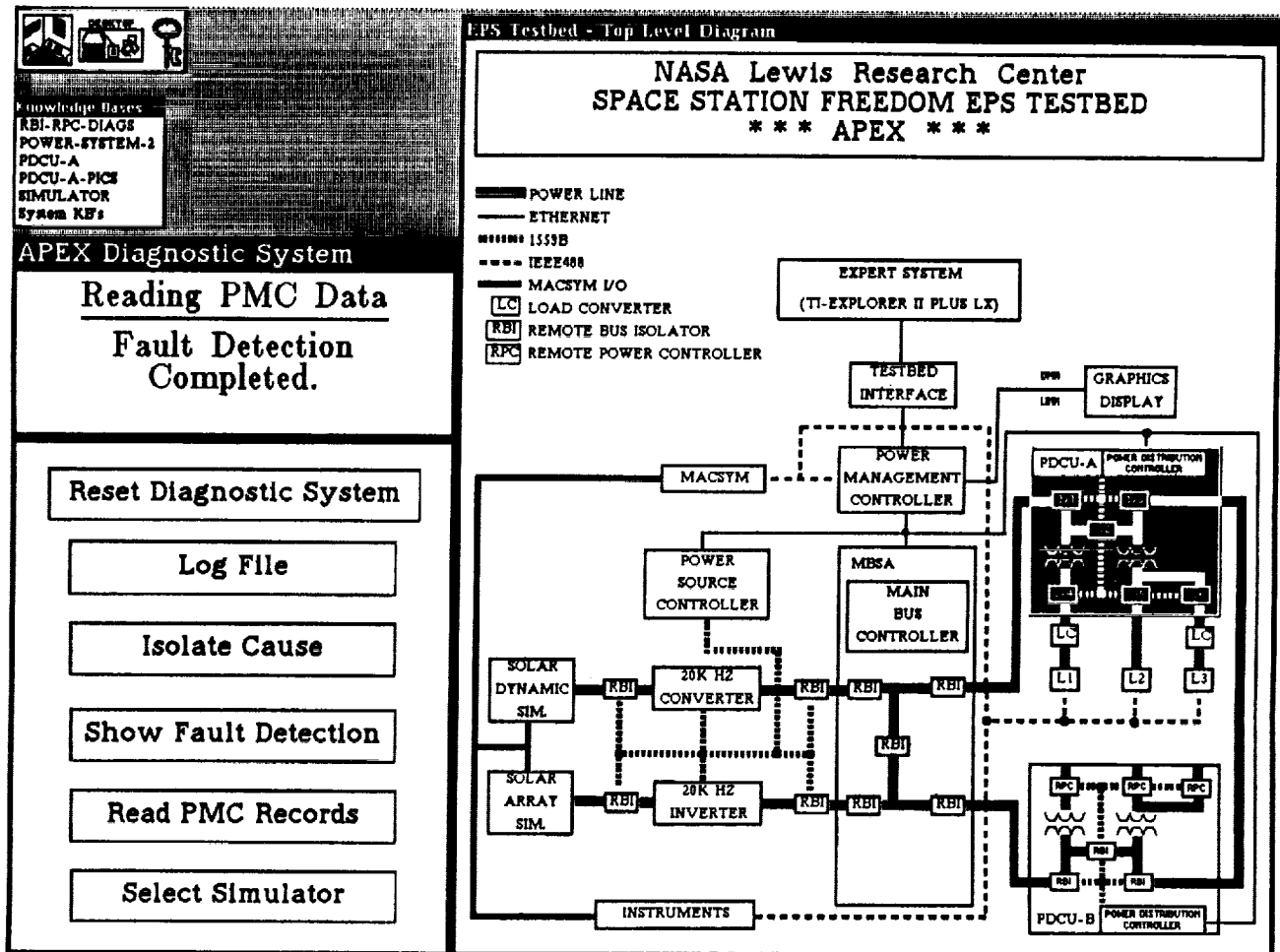


FIGURE 3. - AUTONOMOUS POWER EXPERT (APEX) TOP LEVEL DISPLAY SHOWING OPERATOR PANEL AND ELECTRICAL POWER SYSTEM (EPS) TESTBED.

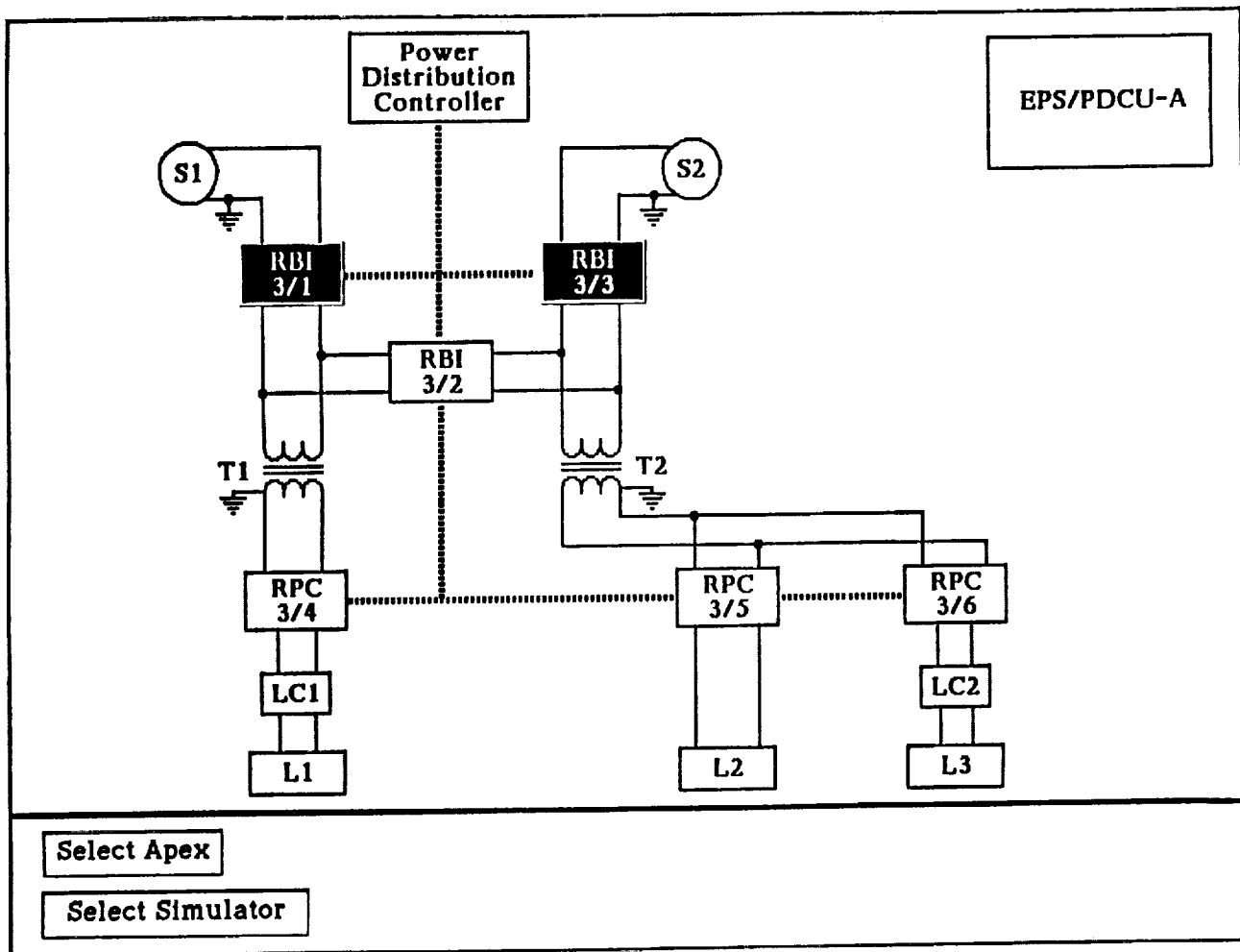


FIGURE 4. - POWER DISTRIBUTION AND CONTROL UNIT SCHEMATIC DIAGRAM SHOWING REMOTE POWER CONTROLLERS (RPC), REMOTE BUS ISOLATORS (RBI), LOAD CONVERTERS (LC), LOADS (L), 20-KHZ POWER SOURCES (S), AND TRANSFORMERS (T).

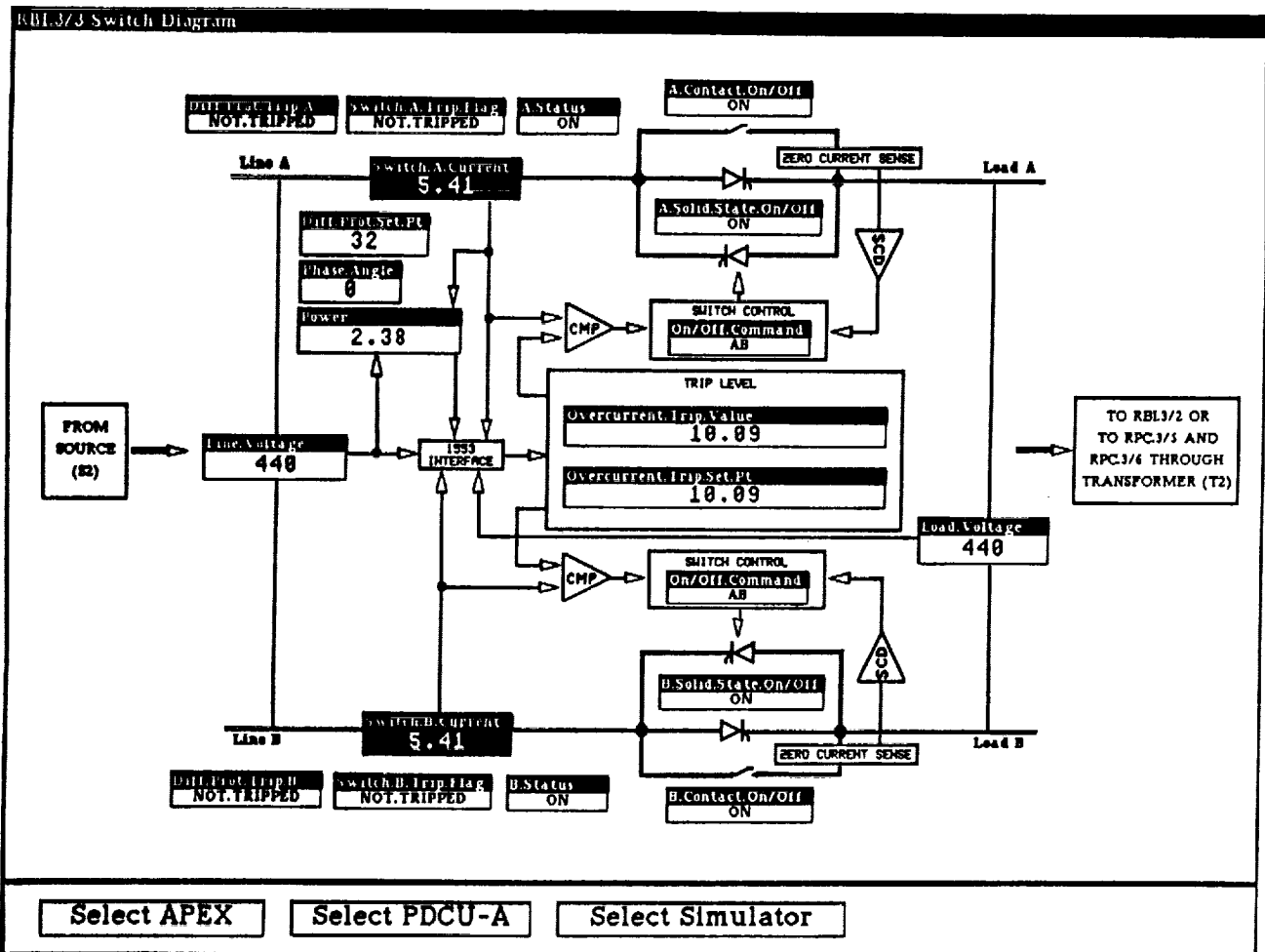


FIGURE 5. - SIMPLIFIED CIRCUIT DIAGRAM OF REMOTE BUS ISOLATOR SHOWING DATA VALUES.

CONCLUSIONS

The Autonomous Power EXpert (APEX) system is fully mouse activated and menu driven for quick and easy operation. Its knowledge bases are well constructed for fast, yet sufficient on-line information. The troubleshooting technique and rules are customized for quick detection and isolation of incipient, and multiple or single faults. Natural language explanations are implemented to show the reasoning applied during the process of isolating faults. These explanations benefit the operator of the testbed by justifying the accuracy of fault isolation conclusions and are reviewed by domain experts to verify proper operation of the APEX system. APEX is also flexible to accommodate changes in the testbed hardware configuration.

Integration of APEX with the PMC and the power resource planner-scheduler is the next logical step. Future expansion of this work could lead

to direct applications and delivery of expert system technology to the full-scale operation of the Space Station Freedom Electrical Power System testbed at NASA Lewis Research Center.

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